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Method to Guide the Design of Project Based Learning Activities Based on Educational Theories*

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Project Based Learning (PjBL) has shown to be effective in engineering to acquire both professional and lifelong learning skills. Nevertheless, some authors assert it is not an easy instructional method to implement. It requires teaching skills and entails some difficulties for both students and teachers, specially related to the time and effort needed to put it into practice. In some countries, the implementation of PjBL has a limited scope, restricted to single courses that do not have a great repercussion in the curriculum. Moreover, some teachers tend to implement PjBL intuitively, based on their teaching experience instead of following important PjBL principles or instructional practices. To facilitate the proliferation and better establishment of PjBL in these countries, it is necessary to engage more teachers in best practices of this methodology, applying its main instructional principles and adequate educational theories. In this way, they could overcome the difficulties mentioned above and obtain better results in their experiences. This study is aimed at defining a method to design activities based on PjBL. This method guides teachers in the use of PjBL principles and several instructional design models. In particular, the method deals with the definition and articulation of an appropriate problem. In addition, it faces three fundamental issues in active learning and especially in PjBL: Students' Motivation, Supporting Students' Work and Autonomous Working. This proposal is specially focused on those academic contexts in which instructors are starting to use this methodology and students are not used to dealing with ill-structured projects, and consequently they could find important difficulties in its implementation. The method has been put into practice in three courses, where first results seem to be satisfactory according to a survey conducted by the Universidad Politécnica de Madrid. Results spanning the last six years of this survey have been analyzed. Currently, it is being used to implement a multidisciplinary project which covers four courses in a Master's degree. Finally, a collaborative online tool and teacher workshop further supports this method.

Keywords: project based learning; instructional design; motivation; PBL support

1. Introduction

1.1 New educational context and project based learning

One of the principles derived from the Bologna Declaration [1] is the need for a teaching style that focuses on the development of student's competences. Several international organizations, for instance the Tuning Project [2], recommend active learning and student-centered methodologies, partially replacing the teacher-centered teaching found in traditional lectures. Among these methodologies, Project Based Learning (PjBL) is highlighted in the engineering context. Many meta-analysis have been made to revise the effectiveness of Problem Based Learning (PmBL): Dochy [3], Newman [4], Gijbels [5], Strobel [6]. From these analyses, we can conclude that PmBL offers better results than traditional teaching in generic competences acquisition, lifelong learning and those tasks in which students have to apply knowledge to real situations. Those studies that are specific to PjBL, Thomas [7], Mills and Treagust [8], Galand [9], Perrenet [10], point to the same advantages than in PmBL. Moreover, they tend to assert that PjBL is more adequate for engineering than PmBL, where professionals usually have to face large and complex projects. Nevertheless, some authors find difficulties in the acquisition of basic engineering concepts if PjBL is used in introductory courses.

Kolmos [11] define three levels to implement Problem/Project Based Learning (PBL) within a curriculum according to its scope. The add-on strategy is focused on the application of PBL within an individual course and carried out by a single teacher or a small teaching team. It is the most widespread strategy since it is relatively easy to implement, without disturbing the existing structure. In the integration strategy, several courses are coordinated to implement a multidisciplinary PBL activity. Moreover, general skills, such as project management or entrepreneurship, are supported within the activity. This implementation requires important changes at subject level, although the curriculum structure is not significantly affected. The most complex strategy is re-building, since it entails more important changes in the organization and academic view. It requires "a shared set of values, identity and commitment" together with strong institutional support. Another proposal is

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presented by Savin-Baden [12], who describes 7 approaches to implement PBL.

1.2 PBL difficulties. Limitation of PBL in Spain and other contexts

As we have discussed previously, PjBL has shown to be effective in engineering education. Nevertheless, its implementation presents some difficulties. We summarize here the main drawbacks pointed out by Hoffman [13], Farnworth [14] and Hammond [15]. Regarding students, PjBL requires a greater effort for them, not only having to gather information by themselves but also facing situations involving complex problems and developing competencies such as problem solving or team work. As far as teachers are concerned, it means a greater cost in terms of redesigning modules, operating classes and assessing students' learning. Hammond [15] concludes that "*To be successful, teachers must provide good scaffolding, and this requires significant skills. But PjBL provides an opportunity to meet the University's wider goals and the expectations of professional engineering institutions*".

In Spain, the scope of PjBL can be qualified as limited. Considering the above-mentioned three levels of PjBL implementation, most of the Spanish experiences belong to the first level, in which a reduced number of motivated teachers apply the methodology to single courses. Certainly, this is due to the difficulties found in traditional structures and regulations within their universities. Thus, we can find several experiences carried out around 10 years ago that illustrate this such as [16] and Macias-Guarasa [17]. A longer experience is described in Lantada [18], where PjBL was initially used in two Civil Engineering courses and recent adaptation increased this PjBL experience to encompass 8 subjects. Nevertheless, it is always applied to singles courses without extending the boundaries of the subject.

Multidisciplinary implementations are not so numerous, but the number has increased over the last years. Whilst before 2010 we could scarcely find a few examples [19, 20], recently more teachers have implemented PjBL covering different courses and disciplines, Perez [21] and Ponsa [22]. Regarding the third level of implementation, the experiences found are related to Master's degrees [23–26], dealing with a reduced number of experienced students. On the contrary, we cannot find undergraduate degrees entirely organized with PjBL. Needless to say, there is a lack of cases where entire universities share the PjBL vision.

Another important clue comes from the participation of Spanish universities in symposiums devoted to PjBL. The International Research Symposium on PBL is a clear example. It is noteworthy that in the four first editions only three Spanish universities were represented (Universidad de Mondragón, Universidad Politécnica de Madrid and Universidad Autónoma de Barcelona), even though the paper presented by the last one was related to Law disciplines. The fifth edition was organized by the Universidad de Mondragón (Spain), so the number of Spanish universities increased to 5 (the three above mentioned plus the Universidad de La Laguna and the Universidad de Salamanca). Nonetheless, the main engineering universities of Spain do not participate in this kind of congresses.

We can conclude that teachers see PjBL as an attractive methodology, since we can find many single experiences, but it does not succeed in having a deep impact on curriculum design. This situation is similar in other countries. This unbalanced diffusion of PjBL can be also perceived in CDIO [27], where experiences are clearly concentrated in Northern Europe, UK, USA and some areas of ASIA whilst seeing a decrease in participation in Southern Europe and South America.

1.3 Definition of the problem and goals

As we have previously discussed, PjBL is not a simple methodology and it requires some teachers' skills. Prince [28] explains this idea: "*Problem-based learning is not an easy instructional method to implement. It requires considerable subject expertise and flexibility on the part of instructors, who may be forced out of their areas of expertise when student teams set off in unpredictable and unfamiliar directions*". Therefore, many lecturers, even considering PjBL an attractive methodology, think they have no time or do not show interest in devoting time to train in PBL. Thus, they end up implementing PjBL in an intuitive way, making the most of their teaching background and their experience in real engineering projects, without following the main PjBL principles and thus only partially implementing the PjBL approach. In our opinion, it is necessary to facilitate the use of PjBL and help new teachers overcome the difficulties described above. In this manner, more teachers will be engaged in good practices of PjBL and better results will be obtained. This could establish the ground in which to boost the PjBL in those contexts in which its reach is limited and thus involve more organizations in the second and third levels of PjBL implementation. We would like to highlight the value of some initiatives such as the Master on PBL of Aalborg University [29]. Nevertheless, this kind of training is attended by already motivated people and it does not involve those teachers who are not in favor of spending too much time and resources on PjBL training. So, from our point of view, other mechanisms are necessary to facilitate the use of PjBL and engage more teachers requiring a moderate effort on their part.

The aim of this paper is to describe a method to design activities based on the PjBL methodology and analyze its effectivity. This method leads instructors in the design of PjBL activities (or courses) by following not only the PjBL principles but also several instructional design theories that help students achieve success in the project development and learning process. From our viewpoint, this method could be especially helpful in academic contexts in which instructors are starting to use PjBL and students are not skilled at dealing with complex and ill-structured projects.

Before designing the method, we must establish some requirements. Firstly, the method should help teachers acquire the new role of facilitator instead of transmitter of knowledge. This is one of the hardest challenges that teachers have to deal with when they are new to PjBL. Secondly, the method should help teachers think about the appropriate support that students need. Such as Hammond [15] asserts, it is a cornerstone of PjBL. Finally, the method should be supported by some kind of tool or guide in order to facilitate its use, since it is focused on engaging new teachers who are not especially motivated to beginning with.

1.4 Solution proposed

We have developed a method that consists of three main phases: Definition, Support and Organization. The goal of the first one is to elaborate the definition of the project, follow the main PBL principles and fulfill the characteristics of good problems. This definition includes not only the goals, but also other information that helps to articulate the project. Subsequently, Support phase is devoted to preparing different learning activities and materials focused on facilitating project success. Finally, Organization phase assists in planning the teaching-learning activities throughout the semester. Each phase is based on several learning theories and tries to coordinate them in order to establish a general process to design the PjBL activities. In particular, we have used: Principles of Problem Based Learning [30–33], Characteristics of good problems [34], Types of problems [35], Motivational Model ARCS [36], Support of problem solving [37] and Autonomous work [38]. The phase of Organization is not a specific goal of this paper, since it was described in previous works. Nevertheless, we will link it to the current study in order to provide a general vision of the complete method.

This method has been used to organize two individual courses: Operating Systems and Real Time Systems, both of which are taught in the Computer Engineering degree. The study is aimed at evaluating the effect this method has on: (1) students' opinion and (2) academic performance. To this end, the following hypotheses were contrasted: (H1) Applying the method to design PBL course activities, students form a better opinion regarding course organization; (H2) Applying the method to design PBL course activities, students have better opinion about teacher performance; H3) Applying the method to design PBL course activities students obtain better academic results.

This paper is structured as follows. Section 2 presents the method's description, illustrating the steps and the theories on which it is based. Besides, additional characteristics and advantages are described, including an introduction to the online PBLT tool. Section 3 describes the methodology used to analyze the three hypotheses and section 4 shows the results obtained in the courses where this method was applied. Finally, in Sections 5 we present the main conclusions and future works.

2. Description of the method to design PjBL activities

2.1 Introduction

There are a large number of proposals to design PBL activities. For instance, [39] specifies seven steps: Introducing the Driving Question; Introducing the Culminating Challenge; Developing Subject Matter Expertise; Doing the Culminating Challenge; Debriefing the Culminating Challenge; Responding to the Driving Question; Summative Assessment. Nelson [40] focuses on collaborative problem solving issues, pointing out the organization of collaborative work. We find the process proposed by Jonassen [41] particularly interesting to design ill-structured problems, which consists of seven steps: (1) Articulate the problem; (2) Introduce problem constraints; (3) Locate, select and develop cases for learners; (4) Support knowledge base construction; (5) Support argument construction; (6) Assess problem solutions.

All these methods describe a series of general steps that are really helpful to design the activity. Although directions are provided in every step, it requires an important effort by the teacher, who still needs skills or experience to put the method into practice. Taking this approach as a starting point and incorporating some instructional design theories, we have designed a new method that provides more detailed directions. As we have already specified, it is divided into three phases (Definition, Support and Organization). Fig. 1 displays these phases, which will be discussed in more detail in following sections.

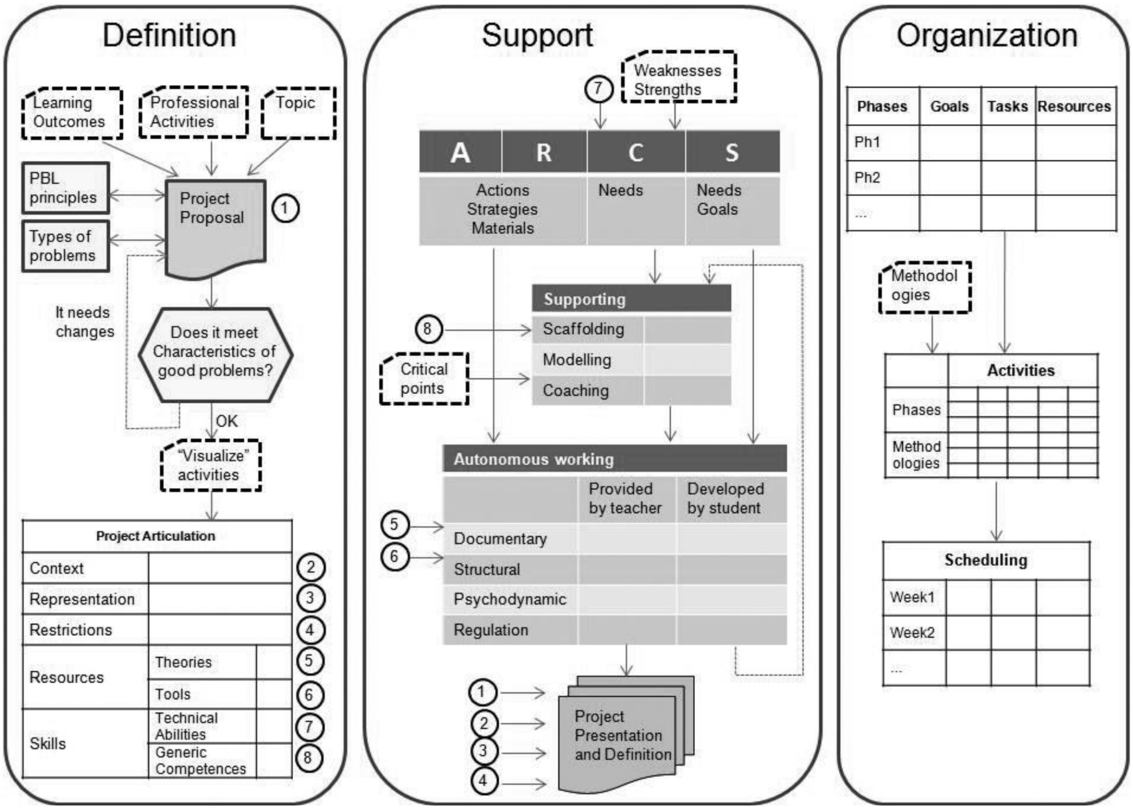

Fig. 1. Schema of the method

2.2 Definition phase

The goal of this phase is to obtain the first project definition, which includes the basic information regarding objectives, restrictions, resources etc. Nevertheless, we start by gathering some previous information: Learning Outcomes of the course, Professional Activities that are carried out in professional contexts related to the course matter and the Topic that we want our students to face. Regarding Professional Activities, Jonassen [35] suggests that it is recommended to engage learners in solving authentic problems, where "*authentic means that learners should engage in activities which present the same type of cognitive challenges as those in the real world*".

2.2.1 Project Proposal

The first Project Proposal specifies the topic, the main goals and the work that must be developed. This proposal is prepared based on PBL principles formulated by Barrows [30] and Kolmos [31] and further developed in De Graaff [32], which are recapped as follows: the use of problems as a starting-point for the acquisition and integration of new knowledge; new information acquired through self-directed learning; student-centered; learning in small groups; teachers acting as facilitators and guides rather than informants; activity-based learning, requiring activities involving research, decision-making and writing; inter-disciplinary learning, extending beyond traditional subject-related boundaries and methods; exemplary practice, ensuring that the benefits for the students are exemplary in terms of the objectives.

At this point in the elaboration of the project we consider it really helpful if teachers know that they can apply different types of problems. This way inexperienced teachers can extend their possibilities, sometimes limited in engineering to the design of a product related to a matter or subject. We highlight two proposals. Jonassen [35] defines eleven types of problems in PBL: Logical problem, Algorithm, Story problem, Rule-using problem, Decision making, Trouble-shooting, Diagnosis-solution, Strategic performance, Cases analysis, Designs and Dilemmas. The author differentiates each type and describes the kind of work that students are expected to develop in each one. These ideas could widen the range of possibilities regarding the design of the problem.

From a different perspective, De Graaff [32] defines three types of projects depending on who is in charge of every task. First, in the Task Project the teacher is who defines both the problem and the method needed to solve it. Moreover, there is a very high degree of planning and direction on the part of the teacher. Second, in the Discipline Project the program requirements establish the discipline and the methods carried out by the students. Students, on their part can identify and define the problem formulation within some guidelines. And third, the Problem Project requires the highest level of student autonomy. Initially a problem-oriented theme is proposed and then students are in charge of choosing the disciplines and methods needed to solve the problem. Although the last type offers important advantages from the point of view of the PjBL methodology, teachers should assess the appropriate kind of project, taking into account several aspects of the academic context.

Then, we check if the proposal elaborated meets the characteristics of a good problem, such as are formulated in Bloom [33] It is engaging and oriented to the real-world; It is ill-structured and complex; It generates multiple hypotheses; It requires team effort; It is consistent with desired learning outcomes; It builds upon previous knowledge/experiences; It promotes development of higher order cognitive skills. According to these characteristics and PBL principles we wonder if some changes are necessary in our proposal to improve it and make it more suitable for a PjBL activity.

2.2.2 Project articulation

Once we have confirmed that the Project Proposal is in tune with these characteristics and principles we move on to articulate the problem, according to Jonassen, [35]. Nevertheless, before tackling this task, we find particularly helpful to ''visualize'' the activities that students will have to carry out when they will face the solution of the project. Sometimes, teachers prefer to implement an almost complete project, similar to the project that will be developed by students. In both cases, the aim is to have an accurate idea about the student's work, its needs, difficulties and other issues that could help us to configure the project.

Project Articulation consists of five sections as described in Fig. 1. We initially describe the context of the project. The relationship of the problem to the social and professional context is an important issue in order for students to understand the relevance. According to Jonassen, [41], a representation or model of the problem can help students understand the starting point and the goals. Restrictions in the development as well as resources that will be needed, both theoretical ground and tools, are included in project articulation. Finally, we describe the skills that students will have to put into practice to develop the project. We distinguish between two kinds of skills. On the one hand, technical abilities are those related to the specific discipline of the course. For instance, testing programs is an important technical skill in computer engineering. On the other hand, Generic Competences are those that are transversal to every discipline, such as Team Working, Problem Solving or Written Communication. Regarding the latter, we propose to include not only those competences that are required by the activities of the project, but also other competences that are specific goals of the degree's curriculum. We dealt with this problem in previous works Perez-Martinez [42], where we proposed a model to incorporate the training, development and assessment of generic competences planned in the curriculum. At this point of the project's articulation we propose to link this model with our method. This issue will be described in more detail in the section Characteristics of the Method.

Numbers specified in the Definition phase are used to identify those parts that will be used in other places. In the Support phase, these numbers together with an arrow indicate where this information coming from the Definition phase is used.

2.3 Support phase

Initially, we gather some information about the main weaknesses and strengths of students who are going to develop the project. This information can be obtained from students who have followed the course in previous years or from previous courses in the curriculum. Weaknesses and strengths are important in designing the PBL support, in order to provide more assistance in those issues where student have more deficiencies.

2.3.1 Students' motivation

Several authors point out motivation as one of the most important issues in education, Ames [43]. Among the different methods or strategies used to motivate students we have obtained satisfactory results with ARCS model [36], so we decided to integrate it into our method. It is focused on promoting and maintaining student's motivation in the learning process. It proposes four steps: Attention, Relevance, Confidence and Satisfaction. First, Keller describes several ways of grabbing students' attention, using a surprise factor and stimulating curiosity. Next, he introduces the relevance of the problem in order to increase learner's motivation. Confidence helps students to understand their likelihood for success. If they feel they cannot meet the objectives or that the cost (time and effort) is too high, their motivation will decrease. Finally, Keller [44] suggests several ideas to make students find satisfaction from their learning.

According to this model we enumerate and describe the actions, strategies and materials that we propose to use to grab the students' attention.

Similarly, we describe the same elements used to highlight and communicate the relevance of their project to the students. Next, we think about students' confidence. In particular, we try to identify the needs of the students in order to gain confidence. At this point, information gathered about technical abilities and weaknesses provide important clues. Applying ARCS model finishes by identifying how we can promote students' satisfaction. What do our students need to feel satisfaction with the project? Based on this question we established some goals around this issue.

2.3.2 Support design

As we discussed in the section PBL Difficulties, designing a helpful support is a keystone to overcome the student difficulties. Jonassen emphasizes this issue in [41]: "*we cannot assume that learners are naturally skilled in problem solving, especially complex and ill-structured problems such as those required in most PBL programs*". If the support is scarce student will find serious difficulties and consequently motivation will decrease. On the other hand, if the support is excessive PjBL will lose the dimension of student self-learning. So teachers should think about the adequate support needed by their students in their context.

However, before dealing with supporting strategies, we propose to analyze the critical points of the project. We identify two types of critical points. First, those tasks or phases in which students find more difficulties, due to its complexity or the student's lack of experience. Second, some points can be cornerstones of the project, and consequently the viability or success of the project could depend on them.

Simons [45] highlights the importance of scaffolding to help students achieve better results in PmBL. Several authors have developed proposals to design scaffolds in different contexts: information seeking [46], problem-solving [47] or reflection [48]. In the case of PjBL, we find it suitable to design the supporting material according to Jonassen model [35]. This author identifies three types of support: scaffolding, modeling and coaching. Modeling is focused on the expert's performance. Behavioral modeling demonstrates how to perform the activities identified in the activity structure, it provides learners with an example of the desired performance. Cognitive modeling articulates the reasoning, decision-making and argumentation that learners should use while engaged in each step of the activity. Coaching is focused on the learner's performance, it consists in accompanying, instructing and training a person to support him while achieving a specific personal or professional competence result or goal. Finally, Scaffolding is focused on the nature of task and the environment. It provides temporary frameworks to support learning and student performance beyond the learner's capacities.

In our case, we propose to first think about the points of the project (phases, tasks, activities etc.) in which students will need specific support. Most of these points can be identified by analyzing the information elaborated regarding confidence needs, generic competences and critical points, such as it is represented in the Supporting Table in Fig. 1. Then, for each one of these points, we think about the most appropriate type of support (Scaffolding, Modeling or Coaching). The question that we try to solve at this step is: What do our students need to overcome these points of the project?

2.3.3 Autonomous work

In the section Project Proposal, we mentioned an important characteristic of PjBL: new information is acquired through self-directed learning. However, we have to balance this issue with other ideas already discussed: sometimes, early year students experience discomfort with the higher level of self-directed learning. At this stage, we propose to think about the level of autonomy we consider appropriate for our students. Therefore, the next step consists in organizing the contents of the course, documents, tools, activities, tasks etc. In particular, we want to determine which contents will be provided by the teacher and which contents are the students responsible for through their autonomous work. Rué [38] classifies these issues into four classes: Documentary (Theories and information needed), Structural (Ideas, rules and tools to act or work), Psychodynamic (It is focused on the relationship among people, members of a group, related to the work) and Regulation (Information necessary to direct and asses or self-asses the work). For every item that we place in one of these categories we can decide if this item will be provided by the teacher or if it should be developed by the students themselves. We will place in the column "Developed by teachers" those things that we know a student cannot do by himself (or in groups) or those that we do not want them to spend time on. On the other hand, those things that students can do with some help from the teacher, their mates or by themselves, will be placed in the column "Developed by the own students".

To integrate this model into our method, we propose to elaborate the table of Autonomous Working taking into account some information compiled in previous steps: actions, strategies and materials used to capture their attention and show relevance; needs and goals to achieve student's satisfaction, all the materials described in supporting section, including any type (Scaffolding, Modeling and Coaching). Moreover, theoretical ground and the tools that are needed in the project must be considered in this section. For each one of the items included in this table we think about the responsibilities of teacher and students. That means, we decide which facilities will be provided by teacher or which activities will be carried out by teacher. On the other hand, we define those materials and activities for which student will be responsible by themselves. This organization is made according to Rué's criteria. Once the table has been completed we suggest reviewing it in other to detect possible lacks in some of the sections. For instance, in some cases Structural and Regulation areas tend to have less items and we could consider adding new activities of facilities that could be useful to reinforce these issues.

2.3.4 Project presentation

To conclude the Support section, we deal with project presentation, which not only consist of those documents that will be handed out to students, but also activities carried out to engage students in the project and make them understand their work and responsibilities. At this step we find relevant the advice presented by Ertmer [49] focused on how to present a project to students: Getting students thinking about the problem before the unit begins, planting seeds of curiosity weeks in advance; To "hook" students through the use of an engaging opening scenario; Program activities to ease students into their new roles and responsibilities; Short problems used to introduce students to the problem-based method; Create "messing about" activities that help students to understand the specific sub-issues embedded within the problem. These actions are more effective than starting "cold" by researching an unfamiliar topic.

In addition to this project presentation, we include a detailed definition of the project, so that students know the kind of work they have to develop, the constraints, final goals, resources provided by teachers, working rules etc. Most of this information is elaborated from the information included in the table Autonomous Work. In this way, the final project definition, one that will be given to students, takes into account the elements elaborated in previous steps. These elements have been pondered according to instructional design theories and advisability in our project.

2.4 Organization phase

This phase consists in planning and organizing the learning activities that will take place throughout the semester, so that we obtain a complete scheduling of the course. Although this process was presented in previous works Garcia [50] we will summarize it briefly in order to provide a complete view of the method. This phase suggests seven steps to design an educational plan. It establishes relationships between every project phase and the educational methodologies that can be used in the course (cooperative learning, laboratory, tutoring, etc.). These relationships are established by means of the learning activities required in each phase (study, reflection, debate, testing, information management and tutoring). It helps to determine which methodology is the most appropriate for each phase of the project and establishes a relation between the work carried out in each phase and the learning activities required to complete it. In conclusion, we chose the most appropriate learning activities for each phase of the project. Finally, we incorporate these learning activities into the semester schedule.

2.5 Some characteristics of the method

In this section, we highlight some additional characteristics that, from our point of view, make the method more useful in some contexts.

- *It guides teachers to follow principles and instructional methods and helps them to acquire the new teacher role.*

From the very first moment the method invites teachers to think about the problem that students have to deal with, based not only on some learning outcomes but also on the professional context. This makes the problem be the center of the activity. The idea of the project is developed and refined taking into account the PmBL principles, a range of different kind of problems and the characteristics of a good problem. The student-centered feature is reinforced by the visualization of the activities. It makes teachers face student motivation from a methodical perspective. Moreover, the instructor is immersed in the new role of facilitator, since he focuses his attention on the kind of support needed by the students and configures their autonomous work.

- *It can be applied to several types of PjBL implementations.*

We have used the term "PjBL activity" since the method can be applied not only to individual courses but also multidisciplinary activities beyond the limits of a single subject. Thus, it can be used in the first two strategies defined in Kolmos [11], the add-on and the integration strategies. Additionally, we think that the method could somehow contribute to achieve the re-building strategy, since it can aid to change the educational vision of teachers, although this strategy requires deeper structural changes. Similarly, it can be applied to the seven Curriculum Modes as defined by Savin-Baden [12]. From a different perspective, it can also be applied to the three types of projects defined by De Graaff [32]: Task Project, Discipline Project and Problem Project. Finally, we draw attention to the fact that the method can be used in a flexible way. The instructor can go into detail about the issues that are considered more important for the project and then superficially specify other non-essential aspects as well as those where the students will be in charge. This feature allows teachers to define their project as an ill-structured problem or closer to a well-structured one, according to their needs and perspectives.

– *It is supported by a collaborative online tool.*

In order to facilitate and support the use of this method, a cooperative tool (PBLT) has been developed at the Escuela Técnica Superior de Ingeniería de Sistemas Informáticos (Universidad Politécnica de Madrid). Although this tool was originally presented in Garcia [51], we will briefly describe some features in order to show the support that this tool provides to the method described in this paper and the relationship between them.

This tool consists of two parts. Firstly, teachers use it to design the activity contents, taking into account the main principles of PmBL methodology. It allows collaborative online work among several instructors, so that they can elaborate the definition of the problem, describe its articulation and design the support with the desired level of detail, including issues such as different materials, references, links to related subjects, planning, milestones or calendar. Secondly, once the course has been designed, teachers generate different instances of the PjBL activity, so that every team of students is attached to an instance. Then, students use the same tool to organize their own project development, including such aspects as planning, tasking, meetings or resource management. The most significant features of PBLT are: to integrate the activities of both teachers (design) and students (development) in the same tool; to offer a collaborative environment for both, teachers' team and students' team; to allow different levels of depth in the project specification, in such a way that teachers can design a project at the desired level between well- and ill-structured; to take into account specific issues of academic contexts, like courses or lessons; to allow remote work.

– *It is supported by a workshop aimed at teachers.*

We have developed a workshop aimed at teachers that starts with a presentation of the main PjBL principles and goals. Through a discussion about the main difficulties and drawbacks of PjBL, participants can understand the meaning of the theories and techniques included in the method. In the course of the workshop, participants have the opportunity to elaborate a draft of their own PjBL educational activity based on the group discussions together with a set of questionnaires and templates. A first version of this workshop was carried out at Northwestern Polytechnical University of Xi'an (China). Nevertheless, more experiences are needed to improve its effectiveness.

– *It is coordinated with a plan to integrate generic competences into a curriculum.*

According to conclusions of previous works [52], in Perez-Martinez [42] a model to integrate generic competences into curriculum was proposed in order to meet EHEE directions. The model consists in developing a map of generic competences according to some precedence relationship. Those competences considered as basic are allocated in the first semesters. In subsequent semesters, more complex competences are introduced based on the basic ones. Once the map is configured, it is projected into the semesters, so that a set of competences is attached to each semester. Afterwards, one or two competences are assigned to each subject. This way every subject is in charge of developing and assessing one or two generic competences specified in the curriculum. Competences are introduced into courses throughout the design of learning activities coordinated with the activities planned in the course.

The method presented in this paper establishes a link with this plan. Initially, the generic competences needed by students to develop the project are identified in the Definition phase, together with other competences assigned to the PjBL activity in coordination with the curriculum. Afterwards, in the Support phase, teachers design the appropriate support to achieve the development of these competences. Coordinating our method with this plan, the PjBL activity designed contributes to develop generic competences and consequently integrates these skills into the curriculum. According to our experience and meta-analysis revised in section 1.1, PjBL is a suitable methodology to improve these kind of competences, such as teamwork, problem solving, oral communication or analysis and synthesis.

3. Research methodology

3.1 Participants and procedure

To carry out this study we have taken samples from two courses: Operating Systems (OS) and Real Time Systems (RTS). OS is a compulsory subject taught during the fifth semester of the degree in Computer Engineering at the Technical School of Computer

Science (Universidad Politécnica de Madrid). We have selected those groups that were taught applying PBL from 2009 until 2014. In 2013 and 2014 the method described in previous sections was used to organize the PBL activities, whilst in 2009, 2010 and 2012 these activities were organized through PBL but without using the abovementioned method. To develop this study, all groups of the same subject were taught by the same teacher, had the same syllabus, shared formative objectives and were assessed with the same criteria. Thus, the only difference consisted in the application of the design method described in a previous section. Using this method, the project definition pays special attention to the motivation and support facilities for students.

In the year 2012, worse results were obtained in OS. Teachers in charge of these courses explained that the theoretical part of the course was organized following Cooperative Learning methodology (in particular the jigsaw technique) and was not well received by students. This fact could influence the students' general opinion about the course. Then, we established three OS groupings in order to develop our analysis. On the one hand OS2014-13, where the method was used and on the other hand, OS2012 and OS2010-09, which followed PjBL but without using the method. In other words, without having a specific motivation and support design. In the subject OS, the tasks which constitute the PBL activities were carried out by groups of 4 or 5 students. This part consists of two projects. The first one is aimed at making a comparison between the process management of the operating systems Windows XP and Linux. In the second one, students implement a library that supports threads management. These projects represented 50% of the final mark. Regarding the theoretical part of the subject, several individual written assessments were performed along the term. Specifically, these consisted in three tests, three short-answer questionnaires and two problems. These assessments were very similar in all courses. The individual mark obtained in these theoretical parts counted for 50% of the final mark.

RTS is an elective subject taught in the eighth semester of the same degree. In this case, PBL has been applied since 2006 but only in the last two years, 2015 and 2014, was the method applied to organize its activities. So, we established two groupings: RTS2015-14 which encompasses the years in which the method was applied and RTS2013-12-11 which includes the three previous years when the method was not applied. RTS is aimed at studying theory principles, techniques and tools required to develop real time systems. Students have to conceptualize a system that provides a solution to a realistic problem. Then they have to design it, implement it and analyze its response times. In the last two years, 2015 and 2014, as a consequence of the method applied, we divided the project into two parts. First, students dealt with the implementation and analysis of the response time of a first case. Then, they faced the conceptualization and design of the final project. These projects constituted 70% of the final mark, whereas a theoretical test and exercise solving represented the remaining 30%.

3.2 Measuring instruments

To analyze the abovementioned hypotheses, two sources of information were used. On the one hand, we used an opinion survey consisting of 17 items. The first 7 items, I1 to I7, gather the student's opinion about the course organization, covering issues such as programmed tasks, theoretical contents, coordination of theory and practices, workload, assessment or feeling of competence improvement. It includes questions such as "Theoretical and practical tasks foreseen in the syllabus have been correctly coordinated" or "I have improved my starting level, regarding the competences established in the course". Items I8 to I17 ask students for their opinion regarding the teacher performance, covering issues regarding quality of the information provided, structure of the programmed activities, help received from the teacher, engagement of students' participation or raising interest in the subject. It includes questions such as "The teacher assistance is effective to learn" or "The teacher achieves to arouse interest in the different topics studied during the learning activity". This survey was developed by the Universidad Politécnica de Madrid and is filled out by students at the end of every semester for any individual course. The survey follows a 6 points Likert scale (1 = not agree at all; 6 = absolute agree).

Although this survey does not directly ask about the method to design PBL activities, we would like to make some considerations. The method is transparent to students, since it is used by teachers to design and organize the PBL activities of the course. Once the course is running, what students perceive is the quality of the course organization and the teacher activities, aspects that are covered by the survey. As we have explained previously, teacher and course contents are the same, the only difference is the organization or not according the method described. Consequently, we are evaluating the influence of the method in the students' perception. For these reasons, we consider that these surveys provide valuable information about the method.

We have analyzed students' performance according to the marks obtained in two facets of both subjects. Firstly, we considered the mark obtained in theoretical tests focused on assessing the acquisition of concepts and exercise solving skills. Secondly, we analyzed the mark obtained in the development of the projects throughout the semester.

The statistical techniques used for the analysis were: Kolmogorov-Smirnov and Shapiro-Wilk were used to determine if data can be adequately modelled by a normal distribution; t-Student with an m+n-2 freedom degree to decide if the equality of the means could be considered in those cases modelled by a normal distribution and Wilcoxon test for independent samples to carry out the equality of the means in those cases that cannot be modelled by a normal distribution.

4. Results and discussion

4.1 Exploratory data

Table 1 displays the exploratory data of every survey item. Columns show the mean, standard deviation and standard error obtained for the three groupings mentioned above: OS2014-13, OS2012 and OS2010-2009. In this case, all variables fit the normal distribution according to Kolmogorov-Smirnov and Shapiro-Wilk tests. Table 2 shows the same exploratory data regarding the academic performance, that is to say, the marks obtained in the theoretical tests (Th) and the marks obtained in the projects (Pr). On the contrary, neither of the variables follows the normal distribution. The lower number of samples in Pr is due to the fact that the projects were developed in teams of 4 students.

4.2 Testing hypothesis H1

Since the variables I1 to I7 fit a normal distribution, we established the equality of means as null hypothesis and run t-Student test for independent variables. Previously, Leven test was used to check equality of variances before running the t-student test and taking the appropriate results. We rejected the equality of variances for I1, I3, I4 and I6. Table 3 shows the results obtained for items I1 to I7 from the groups OS2014-13 and OS2012. Except for item I2, we can reject the null hypothesis (equality of means) for every item between groupings OS2014-13 and OS2012 with p-value $p < 0.05$ for I1 and $p < 0.01$ for the remaining items. In a similar way, Table 4 displays the results obtained from the groups OS2014-13 and OS2010-09. Significant differences were obtained in items I3 to I7 with p-value $p < 0.05$ in I5 and $p < 0.01$ in the other four items. Therefore, we can determine that, in the courses in which the method to design PBL activities was applied, students have better opinion about most of the aspect of the course organization.

Table 1. Opinion Survey Statistics

	OS2014-13 (N = 29)			**OS2012 (N = 24)**			**OS2010-09 (N = 65)**		
	Mean	**Stand. Dev.**	**Stand. Error**	**Mean**	**Stand. Dev.**	**Stand. Error**	**Mean**	**Stand. Dev.**	**Stand. Error**
I1	4.97	0.778	0.145	4.25	1.260	0.257	4.66	1.035	0.128
I2	4.45	0.910	4.45	4.21	1.021	0.208	4.29	0.931	0.115
I3	4.79	4.79	0.188	3.46	1.560	0.318	3.97	1.356	0.171
I4	4.76	4.76	0.137	3.17	1.606	0.328	3.92	1.212	0.152
I5	4.38	4.38	0.188	3.00	1.508	0.314	3.80	1.162	0.144
I6	5.04	0.744	0.141	3.63	1.279	0.261	4.25	1.270	0.160
I7	5.10	0.817	0.152	4.25	1.113	0.227	4.57	0.928	0.117
I8	5.00	0.886	0.165	3.83	1.239	0.253	4.41	1.080	0.135
I9	4.72	1.131	0.210	3.23	1.307	0.279	4.39	1.203	0.150
I10	5.07	0.704	0.131	3.67	1.167	0.238	4.56	1.037	0.130
I11	5.21	0.675	0.125	3.58	1.501	0.306	4.92	0.924	0.115
I12	5.29	0.810	0.153	3.50	1.351	0.276	4.84	0.919	0.116
I13	4.93	1.033	0.192	3.71	1.160	0.237	4.77	1.035	0.129
I14	5.07	0.753	0.140	4.42	1.316	0.269	4.74	0.947	0.121
I15	4.72	0.960	0.178	3.54	0.977	0.199	4.28	0.983	0.123
I16	4.76	0.988	0.183	3.67	1.129	0.231	4.34	0.979	0.122
I17	5.14	0.789	0.147	3.75	1.189	0.243	4.61	0.970	0.121

Table 2. Academic Performance Statistics

	–	**OS2014-13**			–	**OS2012**			–	**OS2010-09**		
	N	**Mean**	**Stand. Dev.**	**Stand. Error**	**N**	**Mean**	**Stand. Dev.**	**Stand. Error**	**N**	**Mean**	**Stand. Dev.**	**Stand. Error**
Th	35	4.931	1.7934	0.3031	28	5.189	1.2245	0.2314	83	5.924	1.4839	0.1329
Pr	14	6.571	2.09741	0.56056	8	7.200	1.40915	0.49821	21	7.538	1.32457	0.28904

Additionally, we compared the Operating Systems groups taught in 2014 and 2013: OS2014 and OS2013. The goal was to test if there is a significant difference between the two groups where method to design PBL activities was applied. Table 5 shows that we could not find significant difference in any of the items. The significance level is clearly higher than 0.05 in all variables.

Finally, we analyzed the opinion survey corresponding to the elective course RTS. Table 6 shows the exploratory data, where every variable fits the normal distribution. Although the mean obtained for every item is higher in those groups that followed the method (RTS2015-14), we obtained significant differences in three out of the seven items with a p-value < 0.05.

4.3 Testing hypothesis H2

As far as the second hypothesis is concerned, we analyzed items I8 to I17. Once again, all these

Table 3. t-student for equality of means between OS2014-13 and OS2012. Course items

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I1	2.426	36.812	0.020	0.716	0.295	0.118	1.313
I2	0.904	51	0.370	0.240	0.265	–0.293	0.773
I3	3.609	38.062	0.001	1.335	0.370	0.586	2.083
I4	4.479	30.993	0.000	1.592	0.355	0.867	2.317
I5	3.934	50	0.000	1.379	0.351	0.675	2.083
I6	4.757	35.731	0.000	1.411	0.297	0.809	2.012
I7	3.215	51	0.002	0.853	0.265	0.321	1.386

Table 4. t-student for equality of means between OS2014-13 and OS2010-09. Course items

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I1	1.572	70.421	0.120	0.304	0.193	–0.082	0.690
I2	0.756	92	0.452	0.156	0.206	–0.254	0.566
I3	2.919	90	0.004	0.825	0.283	0.263	1.386
I4	3.433	91	0.001	0.837	0.244	0.353	1.321
I5	2.318	92	0.023	0.579	0.250	0.083	1.076
I6	3.670	82.143	0.000	0.782	0.213	0.358	1.206
I7	2.649	90	0.010	0.532	0.201	0.133	0.931

Table 5. t-student for equality of means between OS2014 and OS2013

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I1	–1.194	27	0.243	–0.343	0.287	–0.932	0.246
I2	0.927	27	0.362	0.314	0.339	–0.381	1.010
I3	0.408	20.181	0.688	0.152	0.374	–0.627	0.932
I4	0.307	27	0.761	0.086	0.279	–0.487	0.659
I5	0.112	27	0.912	0.043	0.384	–0.745	0.831
I6	0.739	26	0.467	0.210	0.285	–0.375	0.795
I7	–0.247	27	0.807	–0.076	0.309	–0.710	0.557

Table 6. Opinion Survey Statistics of RTS

	RTS2015-14 (N = 25)			**RTS2013-12-11 (N = 37)**		
	Mean	**Stand. Dev.**	**Stand. Error**	**Mean**	**Stand. Dev.**	**Stand. Error**
I1	5.36	0.490	0.098	5.27	0.769	0.126
I2	5.40	0.645	0.129	5.14	0.855	0.141
I3	4.84	0.800	0.160	4.64	1.018	0.170
I4	5.08	0.572	0.114	4.53	1.183	0.197
I5	5.04	0.676	0.135	4.68	1.156	0.190
I6	5.20	0.707	0.141	4.92	0.829	0.136
I7	5.44	0.651	0.130	5.03	0.910	0.152

Table 7. t-student for equality of means between OS2014-13 and OS2012. Teacher items

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I8	3.987	51	0.000	1.167	0.293	0.579	1.754
I9	4.378	49	0.000	1.497	0.342	0.810	2.184
I10	5.161	36.223	0.000	1.402	0.272	0.851	1.953
I11	4.904	30.637	0.000	1.624	0.331	0.948	2.299
I12	5.661	36.406	0.000	1.786	0.315	1.146	2.425
I13	4.057	51	0.000	1.223	0.301	0.618	1.828
I14	2.154	35.029	0.038	0.652	0.303	0.038	1.267
I15	4.428	51	0.000	1.182	0.267	0.646	1.719
I16	3.755	51	0.000	1.092	0.291	0.508	1.676
I17	5.082	51	0.000	1.388	0.273	0.840	1.936

Table 8. t-student for equality of means between OS2014-13 and OS2010-09. Teacher items

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I8	2.590	91	0.011	0.594	0.229	0.138	1.049
I9	1.261	91	0.211	0.334	0.264	–0.192	0.859
I10	2.752	77.064	0.007	0.506	0.184	0.140	0.873
I11	1.485	92	0.141	0.284	0.191	–0.096	0.663
I12	2.204	89	0.030	0.444	0.202	0.044	0.845
I13	0.714	91	0.477	0.165	0.232	–0.294	0.625
I14	1.790	68.022	0.078	0.331	0.185	–0.038	0.700
I15	2.027	91	0.046	0.443	0.219	0.009	0.877
I16	1.887	91	0.062	0.415	0.220	–0.022	0.851
I17	2.572	91	0.012	0.529	0.205	0.120	0.937

Table 9. t-student for equality of means between OS2014 and OS2013

Item	t	gl	Sig.	Mean Difference	Stand. Error.	95% Confidence interval upper	95% Confidence interval lower
I8	0.000	27	1.000	0.000	0.335	–0.688	0.688
I9	0.046	16.762	0.964	0.019	0.415	–0.858	0.896
I10	–1.078	27	0.291	–0.281	0.261	–0.816	0.254
I11	–1.165	27	0.254	–0.290	0.249	–0.802	0.221
I12	–0.594	26	0.557	–0.185	0.311	–0.823	0.454
I13	–1.905	20.706	0.071	–0.686	0.360	–1.435	0.063
I14	0.470	27	0.642	0.133	0.284	–0.449	0.715
I15	0.434	27	0.668	0.157	0.362	–0.586	0.900
I16	–0.143	22.549	0.888	–0.052	0.367	–0.812	0.707
I17	0.922	22.666	0.366	0.267	0.289	–0.332	0.865

variables fit a normal distribution and we established the equality of means as null hypothesis and run t-Student test. Table 7 shows the results obtained for the groups OS2014-13 and OS2012. We can reject the null hypothesis (equality of means) for every item between groupings OS2014-13 and OS2012 with p-value $p < 0.05$ for I14 and $p < 0.01$ for the remaining items. According to Leven test we rejected the equality of variances for I10, I11, I12 and I14. Likewise, Table 8 displays the results obtained for the groups OS2014-13 and OS2010-09. Although the mean is higher in OS2014-2013 in all cases, significant differences were obtained in 5 out of 10 items with p-value $p < 0.05$. As a result, we can determine that in those courses in which the method was applied students, in general, have a better opinion about most of the aspects of teacher performance. However, it is clear that applying the method has less influence in teacher performance than in course organization.

Additionally, we tested the differences between the two Operating Systems groups in which the method to design PBL activities was used: OS2014 and OS2013. Table 9 shows that we could not find significant difference in any of the items with a confidence interval of 95%.

The case of the elective course RTS was quite different. The mean of every item was higher in those courses in which the method was applied (RTS2015-2014) as shown in Table 10. Nevertheless, the difference of means was significant in 3 out of 10 items with a confidence interval of 95%.

Table 10. Opinion Survey Statistics

	RTS2015-14 (N=25)			**RTS2013-12-11 (N=37)**		
	Mean	**Stand. Dev.**	**Stand. Error**	**Mean**	**Stand. Dev.**	**Stand. Error**
I8	5.04	0.841	0.168	4.81	0.967	0.159
I9	5.04	0.790	0.158	4.46	1.406	0.231
I10	5.56	0.507	0.101	4.81	0.938	0.154
I11	5.52	0.653	0.131	5.32	0.973	0.160
I12	5.24	0.663	0.133	5.03	0.845	0.141
I13	4.96	0.562	0.117	4.65	0.789	0.130
I14	5.24	0.597	0.119	5.31	0.867	0.147
I15	5.36	0.757	0.151	4.76	1.116	0.183
I16	5.36	0.757	0.151	4.92	1.038	0.171
I17	5.36	0.638	0.128	5.06	0.984	0.164

Table 11. Statistical contrast for academic performance

	OS2012 vs. OS2014-13		**OS2010-09 vs. OS2014-13**	
	Th	**Pr**	**Th**	**Pr**
U of Mann-Whitney	429.500	41.000	933.000	105.000
W de Wilcoxon	1059.500	146.000	1563.000	210.000
Z	–0.837	–1.026	–3.062	–1.416
Significance (bilateral)	0.402	0.305	0.002	0.157

4.4 Testing hypothesis H3

To test hypothesis H3, the marks obtained by students in theory tests (Th) and in the development of projects (Pr) have been analyzed. In this case we ran the Wilcoxon test, since the variables Th and Pr do not follow the normal distribution. Once again, we analyzed the differences between the groupings that followed the method (OS2014-14) and the other two groups (OS2012 and OS2010-09). Table 11 shows that significant differences were obtained only in the variable Th for groups OS2010-09 and OS2014-13. In this case, the statistic Z has a value of –3,062 with a significance level of 0.002. These results indicate that the mark obtained by students in theory tests is lower in OS2014-13 than OS2010-09, which contradicts the initial hypotheses. Nevertheless, since this is the only significant difference, we conclude that a relationship between the method and the academic performance cannot be deduced from this analysis. Regarding the elective course RTS, significant differences have not been found either.

5. Conclusions and future works

In summary, we have described a method to design activities based on the PjBL methodology. This method guides teachers to apply the main principles of PjBL and several educational theories that help to obtain better results. Among the characteristics of the method, we highlight that it helps teachers acquire the new teacher role, that it can be applied to several types of PjBL implementations and that it is supported by a collaborative online tool as well as an active workshop aimed at teachers. Moreover, it is coordinated with a plan to integrate generic competences into a curriculum.

This method has been applied to two single courses for the last two academic years: the compulsory course Operating Systems (OS) and the elective course Real Time Systems (RTS). We compared the last two academic years to previous years when PjBL was used but without applying the method. In particular, we analyzed students' opinion and students' academic performance. According to these results, students form a better opinion about course organization issues during the years in which the method was applied. Consequently, we consider that hypotheses H1 (Applying the method to design PBL course activities, students form a better opinion about the course organization) is confirmed. This effect is more evident in the compulsory course than in the elective one. We believe that OS underwent a major transformation after applying the method. The RTS surveys had already quite high results in years previous to applying the method. Moreover, students have a greater appreciation for these kinds of changes in compulsory courses than in elective ones. Regarding the second hypotheses, applying the method affects teacher performance to a lesser extent than course organization. Students showed better opinion in half of the items. These outcomes are perceived in both, the compulsory and the elective courses, which allows us to conclude that H2 (Applying the method to design PBL course activities, students have better opinion about the teacher performance) is partially confirmed. In both courses, compulsory and elective, significant differences in students' academic performance were not detected in the project development mark. We only detected significant difference in the mark obtained in theoretical tests in one group, but this difference was in favor of the group that did not use the method. Consequently, hypotheses H3 (Applying the method to design PBL course activities students obtain better academic results) cannot be confirmed. We believe that general academic performance depends on many factors, not only on the design and support of the project. Probably, we would need other kind of analysis to compare more specifically the quality of the projects.

In conclusion, using the method to design PBL activities seems to improve students' perception of course organization and, in lesser extent, of teacher performance. On the contrary, it does not improve academic performance of students. Yet, taking into account teachers' opinion, the method appears to be useful to help students overcome the main difficulties when they are facing complex and ill-structured projects. Teachers devote more attention to analyze the support needed by students to overcome these difficulties and improve their motivation.

As far as future work is concerned, the first and most important task is to integrate assessment procedures within the method. We have not yet included this key issue in the first version of the method but we are aware of its relevance in PjBL.

More experiences will be carried out in the shortly. During the year 2015–2016 the method has been put into practice to organize a multidisciplinary project integrated in the Master in Distributed and Embedded Systems Software (UPM). The project developed by students is the central activity to teach four courses: Software Engineering, Embedded Systems, Control Systems and Real-Time Systems. Although the reduced number of students does not allow us to obtain quantitative results, we hope to gather opinions regarding advantages and drawbacks that will help us improve the method. In the near future, we foresee a reorganization of this master following a PjBL vision. The method will be applied to organize a master degree curriculum and to design further multidisciplinary projects within the undergraduate degree. In addition, more workshop sessions will be programmed. This will allow us to get more feedback from participants as well as monitor the influence of the workshop in their academic contexts.

References

1. Joint declaration of the European Ministers of Education Convened in Bologna on the 19th of June 1999, European Ministers of Education, http://www.magna-charta.org/resources/files/text-of-the-bologna-declaration, Accessed 10 January 2016.
2. Tuning Project. Website University of Deusto, http://www.unideusto.org/tuningeu/, Accessed 10 January 2016.
3. F. Dochy, M. Segers, P. Van den Bossche and D. Gijbels, Effects of problem-based learning: a meta-analysis. *Learning and instruction: the journal of the European Association for Research on Learning and Instruction*, **13**(5), 2003, pp. 533–568.
4. M. Newman, A pilot systematic review and meta-analysis on the effectiveness of Problem Based Learning, Learning & Teaching Subject Network-01, Newcastle, 2003, p. 72.
5. D. Gijbels, F. Dochy, P. Van den Bossche and M. Segers, Effects of problem-based learning: A meta-analysis from the angle of assessment, *Review of Educational Research*, **75** (1), 2005, pp. 27–61.
6. A. Walker and H. Leary. A Problem Based Learning Meta Analysis: Differences Across Problem Types, implementation Types, Disciplines, and Assessment Levels, *Interdisciplinary Journal of Problem-Based Learning*, *Special Issue on the Efficacy of Problem-Based Learning*, **3**(1), 2009.
7. J. W Thomas, A Review of Research on Project-Based Learning, http://www.bie.org/research/study/review_of_project_based_learning_2000, Accessed 10 January 2016.
8. J. E. Mills and D. F. Treagust, Engineering Education—Is Problem-Based or Project-Based Learning the Answer?, *Australasian Journal of Engineering Education*, **3**(2), 2003, pp. 2–16.
9. B. Galand, M. Frenay and B. Raucent. Effectiveness of Problem-Based Learning In Engineering Education: A Comparative Study on Three Levels of Knowledge Structure. *International Journal of Engineering Education*, **28**(4), 2012, pp. 939–947.
10. J. C. Perrenet, P. A. J. Bouhuijs and J. G. M. M. Smits, The Suitability of Problem-based Learning for Engineering Education; Theory and Practice, *Teaching in Higher Education*, **5**(3), 2000, pp. 345–358
11. A. Kolmos, R. G. Hadgraft and J. E. Holgaard, Response strategies for curriculum change in engineering, *International Journal of Technology and Design Education*, **25**(4), 2015, pp. 1–21.
12. M. Savin-Baden, Challenging Models and Perspectives of Problem-Based Learning, *Management of Change*, Sense Publishers, Rotterdam / Taipei, 2007.
13. B. Hoffman and D. Ritchie, Using multimedia to overcome the problem with problem based learning, *Instructional Science*, **25**, 1997, pp. 97–115.
14. C. Farnsworth 1994, Using computer simulations in problem-based learning, *Thirty-Fifth ADCIS Conference* Nashville, 1994, pp. 137–140.
15. M. Hammond, Problem-Based Learning in the Engineering Curriculum—Is it suitable for first year undergraduates? Inspiring Academic Practice. https://education.exeter.ac.uk/ojs/index.php/inspire/article/view/9/5, Accessed 10 January 2016.
16. Sistemas Operativos Plan 1996 (PBL), http://laurel.datsi.fi.upm.es/docencia/asignaturas/sopbl, Accessed 10 January 2016.
17. J. Macias-Guarasa, R. San-Segundo, J. A. Montero, J. Ferreiros and R. Cordoba, Tools and Strategies for Improving PBL Laboratory Courses with a High Student-to-Faculty Ratio, *35th ASEE/IEEE Frontiers in Education Conference*, Indianapolis, USA, 2005, pp. 19–22.
18. A. D. Lantada, P. Lafont-Morgado, J. M. Munoz-Guijosa, J. L. Munoz-Sanz, J. Echavarri-Otero, J. Muñoz-Garcia, E. Chacon-Tanarro and E. de la Guerra Ochoa, Towards Successful Project-Based Teaching-Learning Experiences in Engineering Education, *International Journal of Engineering Education*, **29**(2) 2013, pp. 1–15.
19. Nuevas metodologías docentes ante el EEES: Aprendizaje

Basado en Proyectos y su Implementación con Tecnologías para el Trabajo Colaborativo. Proyectos de Innovación Tecnológica-Educativas. http://web.ua.es/es/i3a/proyectos/aprendizaje-basado-en-proyectos.html, Accessed 10 January 2016.
20. Aplicación del Aprendizaje Basado en Problemas (PBL) Bajo un Enfoque Multidisciplinar: una Experiencia Práctica, http://dialnet.unirioja.es/servlet/articulo?codigo=2232506, Accessed 10 January 2016.
21. L. Perez Urrestarazu, A. Franco Salas and R. Fernandez Canero, Multidisciplinary Education for New Landscape. Engineering Concepts using Problem-Based Collaborative Learning. A Case Study in Spain, *International Journal of Engineering Education*, **27**(1), 2011, pp. 138–145.
22. P. Ponsa, B. Amate, J. A. Roman, S. Oliver, M. Diaz and J. Vives, Higher Education Challenges: Introductionof Active Methodologies in Engineering Curricula. *International Journal of Engineering Education*, **25**(4), 2009, pp. 799–813.
23. Máster en Estrategias y Tecnologías para el Desarrollo UPM y UCM. http://www.itd.upm.es/masteretd/un-aprendizaje-basado-en-proyectos-reales-de-desarrollo/, Accessed 10 January 2016.
24. Master Universitario en Ingeniería Industrial. Universidad de La Rioja. http://www.unirioja.es/estudios/master/852M/, Accessed 10 January 2016.
25. Máster Universitario en Ingeniería Industrial. Univ de Mondragón. http://www.mondragon.edu/es/estudios/master/master-universitario-ingenieria-industrial, Accessed 10 January 2016.
26. Máster universitario en Ingeniería de Automoción. Universidad Politécnica de Cataluña**.** https://automocio.masters.upc.edu/es, Accessed 10 January 2016.
27. The CDIO Initiative, http://www.cdio.org/, Accessed 10 January 2016.
28. M. J. Prince and M. Felder, Inductive Teaching and Learning Methods: Definitions, Comparisions and Reaearch Bases, *Journal on Engineering Education*, **95**(2), 2006, pp. 123–138.
29. Master in Problem Based Learning, http://www.mpbl.aau.dk/, Accessed 10 January 2016.
30. H. Barrows, Problem-based Learning in Medicine and Beyond: A Brief Overview, *New directions for teaching and learning*, **68**, 1996, pp. 3–12.
31. A. Kolmos, Changing the Curriculum to Problem-Based and Project-Based Learning, *Outcome-Based Science, Technology, Engineering, and Mathematics Education: Innovative Practices*, 2012, pp. 50–61.
32. E. De Graaff and A. Kolmos, Characteristics of problem-based learning. *International Journal of Engineering Education*, **19**(5), 2003, pp. 657–662.
33. B. S. Bloom, Taxonomi of Educational Objectives, *The Classification of Educational Goals. Handbook 1: Cognitive Domain*. David Mckay Company, New York, 1956.
34. A. Kolmos, E. De Graaff and X. Du, Diversity of PBL-PBL learning principles and models, in Xiangyun Du, Erik de Graaff and Anette Kolmos (eds), *Research on PBL practice in engineering education*, Sense Publisher, Rotterdam, 2009, pp. 1–7.
35. D. Jonassen, Supporting Problem Solving in PBL. *Interdisciplinary Journal of Problem-based Learning*, 2011, **5**(2), pp. 95–119.
36. J. M. Keller, Motivational Design of Instruction, in C. M. Reigeluth (eds) *Instructional-Design Theories and Models*, Lawrence ErlBaum Associates, Publishers, Hillsdale New Jersey, London, 1983, pp. 383–434.
37. D. Jonassen, Designing Constructivist Learning Environments. *Instructional Design theories and Models Vol II*. Edited by C. M. Reigeluth, Lawrence Erlbaum Associates, 1999.
38. J. Rué, El Aprendizaje Autónomo en Educación Superior. *Narcea, S. A. de Ediciones*, España, 2009.
39. Edutopia. Practical PBL Series: Design an Instructional Unit in Seven Phases. http://www.edutopia.org/blog/practical-pbl-design-amber-graeber. Accessed 10 January 2016.
40. L. M. Nelson, Collaborative Problem Solving. *Instructional-Design theories and Models Vol II*. Edited by C. M. Reigeluth, Lawrence Erlbaum Associates, 1999.
41. D. Jonassen, Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes. *ETR&D*, **45**(1), 1997, pp. 65–94.
42. J. E. Perez-Martinez, J. Garcia Martin and A. Lias Quintero, Integrating Generic Competences into Engineering Curricula. *The international Journal of Engineering Education*, **30**(6B), 2014, pp. 1636–1644.
43. C. A. Ames, Motivation: What teachers need to know, *Teacher College Record*, **91**(3), 1990, pp. 409–421.
44. J. M. Keller, Motivational Design for Learning and Performance: The ARCS Model Approach. Springer, USA, 2010.
45. K. D. Simons and J. D. Klein, The Impact of Scaffolding and Student Achievement Levels in a Problem-based Learning Environment, *Instructional Science*, **35**(1), 2007, pp. 41–72.
46. S. E. Wolf, The Big Six Information Skills as a metacognitive scaffold in solving information-based problems, Unpublished doctoral dissertation, Arizona State University, Tempe, Arizona, 2000. http://eric.ed.gov/?id=ED455800, Accessed 10 January 2016
47. K. L. Cho and D. Jonassen, The effects of argumentation scaffolds on argumentation and problem solving, *Educational Technology Research and Development*, **50**(3), 2002, pp. 5–22.
48. E. A. Davis and M. C. Linn, Scaffolding students knowledge integration: Prompts for reflection in KIE, *International Journal of Learning*, **22**, 2000, pp. 819–837.
49. P. A. Ertmer, Scaffolding Teachers' Efforts to implement Problem-Based Learning. *International Journal of Learning*, **12**(4), 2005, pp. 319–328.
50. J. Garcia and J. E. Perez, A PBL Application Experience Supported by Different Educational Methodologies, in Xiangyun Du, Erik de Graaff and Anette Kolmos (eds), *Research on PBL Practice in Engineering Education*, Sense Publisher, Rotterdam, 2009, pp. 139–150.
51. J. Garcia, C. Lopez and J. E. Perez, Supporting the design and development of Project Based Learning courses, *44th annual Frontiers in Education Conference*, Oct. 22–25, Madrid, Spain, 2014, pp. 2414–2419.
52. J. García, M. Bollaín and A. Corral, Applying problem-based project-organized learning in a traditional system, *3rd International Research Symposium on PBL*, Coventry University, UK, 2011, pp. 684–676.

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